AN ALGAL SURVEY OF SURFACE WATERS IN EASTERN MONTANA SUSPECTED TO BE INFLUENCED BY SALINE SEEP, WITH SPECIAL EMPHASIS ON SALINITY INDICATORS AND POTENTIALLY TOXIC SPECIES

Final Report to The Old West Regional Commission, The Montana Bureau of Mines and Geology, and The Water Quality Bureau, Montana Department of Health and Environmental Sciences

by

Loren L. Bahls and Peggy A. Bahls
1032 Twelfth Avenue
Helena, Montana 59601

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ABSTRACT

One hundred samples of benthic algae were collected from surface waters in eastern Montana suspected of being influenced by dryland salinity. The class Bacillariophyceae (diatoms) was the most abundant and diverse group, dominating 62 percent of the samples and represented by 291 distinct taxa in 38 genera. Diatom species diversity was inversely correlated with specific conductance and the relationship was significant to the 1 percent level of probability. Several taxa with documented brackish water affinities were among the more common diatoms encountered. The spectrum of salinity values for the waters surveyed (332-42519 mg/l TDS) eclipsed the maximum and minimum tolerances for many of the diatom taxa described. Although blue-green algae comprised a relatively minor portion of the total flora, potentially toxic taxa were present in 25 of the 100 collections. A determination of the immediate threat to livestock from consumption of waters containing these algae and documentation of possible toxic algae blooms in stockponds across eastern Montana could not be accomplished given the methods employed in this survey. Proposals are made for educating ranchers on the potential toxic algae problem and for establishing a biological salinity impact monitoring network.

TABLES AND FIGURES

INTRODUCTION

This report describes the attached or benthic algae (phycoperiphyton) found at 100 different sites on a variety of surface waters in eastern Montana suspected of being influenced by dryland salinity. Most of the waters sampled were small first and second-order streams, however they ranged in size from tiny spring seeps to the Missouri River at the Fred Robinson Bridge. An assessment is made of the susceptibility of livestock and wildlife to potentially toxic blue-green algae encountered in these waters. Diatom taxa useful as salinity indicators are identified and their respective salinity tolerances are described.

Salinity in surface and groundwaters is a well-known and long-standing problem in eastern Montana. In recent years salinity levels in certain waters have been increasing (5, 15). It is believed that a major contributor to this growing problem is the process called saline seep (4, 9, 20).

Salinization of surface waters used by livestock has been implicated in recent reports of cattle deaths near stock ponds in saline seep areas (29). These waters, in addition to the high concentrations and array of dissolved minèrals and nutrients they are known to contain, may harbor strains of blue-green algae that are lethal to livestock and wildlife following water blooms (7, 19, 22, 31). Species containing suspected toxic strains are known to occur in a broad band across the northern United States and southern Canada, and may be found in waters having a total dissolved solids content of up to 20,000 mg/l (25, 26).

The primary objective of this survey was originally to determine whether potentially toxic blue-green algae regularly form water blooms in reservoirs frequented by livestock and, if they do, what factors contribute to such blooms. Their occurrence in waters affected by irrigation or dryland salinity may present an additional and unsuspected operating hazard to eastern Montana livestock producers. Small streams in eastern Montana are often intermittent and cannot be relied on as a source of stock water the year round. Impounded in reservoirs, water is available for all of the ice-free season. Most potentially toxic species of blue-green algae are planktonic and realize their full lethality only following a bloom in the open, standing water of lakes and reservoirs (7). It was therefore proposed initially that at least 50 of the 100 algae samples be taken from the plankton of stock-watering reservoirs (3). Unfortunately, due to time and access limitations, only a handful of samples (eight) were collected from such waters; all were taken from the periphyton and none were taken from the plankton. Consequently, the results from this phase of the survey are inconclusive.

However, another useful purpose has been served by completion of this survey. Algae, particularly diatoms, are useful as monitors of water quality. Because they directly utilize dissolved minerals and nutrients in their metabolic proceses, they are orders of magnitude more sensitive to changes in the ambient concentrations of these elements than either invertebrates or fish. They reproduce much faster than invertebrates or fish, hence their response is more immediate. They are also less mobile and less able to evade the consequences of pollution. As biological organisms they integrate the effects of all the various physical and chemical factors to which they are exposed. The envrionmental requirements and pollution tolerance of many freshwater diatoms have been documented (17). The absence, or when present the relative abundance, of certain species and varieties may indicate specific water quality conditions.

The waters sampled in this survey vary in salinity[1] from levels typical of fresh water to and exceeding those of sea water. Given such a broad range in total ionic load, the correlation of dissolved solids and electrical conductivities of these waters with the relative abundances of their more common diatom taxa will make it possible to identify certain species and varieties that may serve as salinity indicators. Such taxa may be used in lieu of or in concert with physico-chemical analyses as markers of salinization in surface waters of eastern Montana.

One incidental benefit will accrue from completion of this survey. It will enhance our knowledge of the distribution of diatoms in Montana and will represent a significant contribution to a statewide diatom flora now in initial stages of preparation.

METHODS

One hundred samples of benthic (attached) algae were collected from 100 different sites in eastern Montana by personnel of the Water Quality Bureau (Montana Department of Health and Environmental Sciences), the Montana Bureau of Mines and Geology, and by this writer. Dates and locations of algae samples are listed in Appendix A. Collectors were instructed to sample macroscopic algae in proportion to their abundance at a given site and to scrape microscopic algae from natural substrates roughly in proportion to the importance of each substrate (rocks, mud, etc.) at each site, thus giving a representative composite sample (2). Substrates were scraped with a carefully cleaned scalpel or

[1]The salinity of an inland water may be regarded as the concentration of all the ionic constituents present, according to Hutchinson (13).

pocket knife. Samples were labelled, preserved with Lugol's (IKI) solution and shipped to Helena for microscopic analysis. In most cases a water sample was collected on the same date as the algae sample. Water samples were analyzed for dissolved solids and electrical conductivity at the Department of Health laboratory in Helena. In some cases, field conductivity measurements accompanied the algae sample.

Algae samples were analyzed microscopically as follows. Macroscopic filamentous algae were placed on a glass slide roughly in proportion to their abundance in the sample. The sample was then agitated and an aliquot of suspended microscopic algae was pipetted onto the same slide. A coverslip was added and this "wet mount" was scanned under low magnification (100X) to estimate the relative importance of algal taxa in the sample. (A magnification of 400X was used for critical identification of taxa.) Whenever possible the more common taxa were assigned an order of rank. At this stage diatoms were considered as a group and all other algae were identified and ranked at the level of genus.

The remainder of the sample was then "cleaned" in a mixture of concentrated sulfuric acid and potassium dichromate. This process effectively oxidizes all the organic contents of the ornamented silica diatom frustules, which is necessary for accurate identification and enumeration. Following repeated decantation and dilution with distilled water, the cleaned sample was thoroughly mixed and a few drops pipetted onto a coverslip. When all moisture on the coverslip had evaporated, a permanent mount was prepared by inverting the coverslip on a heated glass slide containing two drops of a high refractive index mounting medium. The slide was labelled and then stored to await detailed diatom analysis.

The permanent diatom slide was scanned, first under low dry (100X) and then under oil immersion (1,000X), and a list was prepared of those taxa that could be found within a reasonable length of time, usually 30 minutes. Diatoms were identified to species, and to variety and form where appropriate and possible using available keys (10, 23, 24). Once a diatom flora was prepared for the site, the slide was examined under oil immersion beginning at one edge of the coverslip until at least 100 frustules were identified and enumerated. Work by McIntire and Overton (18) indicated that 100 is about the samllest sample size that one can use and still yield diversity and relative abundance values reasonably representative of the diatom association as a whole. Percent relative abundance values were calculated for each taxon and two diversity indexes were calculated for each sample:

Margalef's index (8)

$$D = \frac{S - 1}{\ln N}$$

and Simpson's index (28)

$$SD = 1 - \sum_{i=1}^{S} \left(\frac{n_i}{N} \right)^2$$

where S is the number of species, N is the total number of individuals in the sample, and n_i is the number of individuals in the i-th species. Percent relative abundance and frequency or occurrence were calculated for each taxon over all 100 samples. These two statistics were then multiplied giving an abundance-occurrence index, which is directly related to the chances of finding that particular taxon at any one of the 100 sites (1).

At those sites where water samples were taken, species relative abundance and diversity statistics were correlated with specific conductance (SC) values. Salinity optima and ranges of the more common taxa were expressed in terms of total dissolved solids (TDS). Only these two estimators of ionic load were selected for comparison because it is unlikely, over the wide range of salinity encountered, that any other water quality parameters would be as effective at determining species diversity or relative abundance. Temperature and nutrients, considered initially (3) because they are known to be significant in promoting blooms of blue-green algae (14), were not used in this analysis because (i) the plankton community was not sampled, (ii) no known water blooms were sampled, (iii) blue-green algae were only a small fraction of the entire flora, and (iv) spot temperature measurements could not have been used with confidence because of temperature's tendency to undergo marked diurnal fluctuation.

RESULTS

Non-diatom Algae

Non-diatom algae in six major groups and 57 genera were encountered' in the periphyton at the 100 localities sampled. A complete list of genera is in Appendix B. Because the plankton community was not sampled, the great majority of these genera are attached forms, however a few incidental plankters were encountered.

Table 1 gives the rank frequency of the most prominent non-diatom algal genera. As a group the green algae were the most important among the non-diatoms, and *Cladophora* was the most abundant non-diatom genus. Following the greens, the blue-greens, chrysophytes, euglenoids, red algae, and cryptomonads were the other non-diatom groups in descending order of abundance. Besides *Cladophora*, other significant non-diatom genera were *Rhizoclonium* and *Spirogyra* among the greens,

Table 1. Rank frequency of diatoms and prominent non-diatom genera in the periphyton of surface waters suspected to be influenced by saline seep in eastern Montana.

	Rank 1	2	3	4	5
Diatoms (Bacillariophyceae)	62	22	12		
Chlorophyta	24	15	7	5	2
Chara	1				
Chlorococcum				1	
Cladophora	10	1			
Closterium		1		1	
Enteromorpha	1			1	
Gloeocystis		1			
Hormidium		1			1
Mougeotia		1	2		
Oedogonium	1	1			
Platymonas	2		1		
Rhizoclonium	4	4	1	1	1
Sphaerocystis				1	
Spirogyra	4	1	2		
Stigeoclonium	1				
Ulothrix		3	1		
Zygnema		1			
Cyanophyta	7	17	10	3	
*Anabaena	1	1	1		
*Aphanizomenon		2			
*Lyngbya	1				
*Nostoc			1		
Oscillatoria	4	7	3		
Phormidium	1	4	2	1	
Rivularia		1		2	
Spirulina		1	3		
Tolypothrix		1			
Chrysophyta	6	1	1		
Chrysococcus	1				
Tribonema	2	1	1		
Vaucheria	3				
Euglenophyta	1	1	1		1
Euglena	1	1	1		1
Rhodophyta		1			
Audouinella		1			

*Genera containing species of blue-green algae suspected of producing strains that are toxic to livestock or wildlife.

and Oscillatoria and Phormidium among the blue-greens.

The freshwater blue-green algae suspected of producing strains toxic to wildlife or livestock are listed in Table 2. Six of the genera included on this list (Anabaena, Aphanizomenon, Gomphosphaeria, Lyngbya, Nodularia, and Nostoc) were encountered in 25 of the 100 samples (see Appendix A). Four of these genera--Anabaena, Aphanizomenon, Lyngbya, and Nostoc--were important enough to be ranked in Table 1. None was present in the massive concentrations typical of a bloom, however, verification of the presence or absence of a bloom cannot be accomplished without sampling the plankton community or without some record of the collector's visual observations. Nevertheless, potentially toxic bluegreens apparently comprised a relatively minor portion of the overall algal flora in the waters sampled.

Only one suspected toxic blue-green alga--Aphanizomenon flos-aquae--was identified conclusively to species. A. flos-aquae was found in two of the eight standing waters sampled (Appendix A). It ranked second both times although the colonies were fragmented and appeared to be in a senescent condition. Samples at these locations may have been taken shortly after the peak of a water bloom when many colonies of this ordinarily planktonic species had sunk to the bottom. Of the species thought to produce toxic strains, there is less evidence to implicate A. flos-aquae than any of the others; it is not known with certainty whether this taxon can be toxic (7).

The Diatom Flora

Diatoms representing 38 genera in 291 distinct taxa were identified in the 100 periphyton collections. Many additional taxa were recognized but could not be identified using available keys. About 60 per-

Table 2. Freshwater blue-green algae suspected of producing strains that are toxic to wildlife or livestock.

Taxon	References
Anabaena	19, 22
A. circinalis	22
A. flos-aquae	7, 22, 31
A. lemmermannii	7, 22, 31
Anacystis (Microcystis)	19, 22
A. aeruginosa	7, 19, 31
A. cyanea	22
Aphanizomenon flos-aquae	7, 19, 22, 31
Coelosphaerium	19
C. kutzingianum	7, 31
Gloeotrichia	19
G. echinulata	7, 22, 31
Gomphosphaeria	19
G. lacustris	22
Lyngbya	19
L. contorta	22
Nodularia	19
N. spumigena	7, 19, 22, 31
Nostoc rivulare	19

cent of these taxa were the same as those reported by Hustedt from a number of saline lakes in Europe (11, 12). As a group, diatoms ranked among the first three most important algae in 96 of the 100 samples; diatoms ranked first 62 times, second 22 times, and third 12 times. Overall, it was the most abundant and diverse group of algae in the waters that were sampled. (See Table 1 and Appendix B for abundance and diversity of other algae groups.)

Percent relative abundance, percent frequency of occurrence, and the abundance-occurrence index for each of the 291 diatom taxa are listed in Appendix C. Relative abundance values are based on a total count of 15,185 individual frustules (cells); frequency values are based on a total of 100 samples. <u>Achnanthes minutissima</u> had the highest relative abundance value, contributing slightly less that 10 percent (9.53 percent) of all the frustules counted. <u>Nitzschia palea</u> was the most frequently occurring diatom, found in 90 of the 100 samples. The maximum possible abundance-occurrence value would be 100 percent relative abundance times 100 percent frequency equals 10,000. N. palea ranked first in abundance-occurrence (607.50) and A. minutissima ranked second (409.79). In all, only 18 taxa had abundance-occurrence values greater than 50. These taxa are given in Table 3. They may be considered the most common taxa in waters subject to saline seep in eastern Montana. Except for those with a broad ecological amplitude, they are also the ones most amenable for comparison with water quality parameters and the ones most useful as indicators of surface water salinization.

Salinity and the Diatom Community

Specific conductance (SC) measurements, either field or laboratory, were available for 94 of the 100 waters sampled. Total dissolved solids (TDS) measurements were available for 57 of those same 94 waters. Because water use criteria for livestock, irrigation, and human consumption are more commonly expressed in TDS rather than SC, it was desirable to convert SC to TDS in those instances where TDS values were not available and SC values were. Assuming a linear relationship exists between the two parameters a regression equation was calculated using the 57 pair of measurements:

$$TDS = 0.85\ SC \div 19$$

The remaining SC values were then entered individually and the equation solved for TDS.

Margalef (D) and Simpson (SD) diversity indexes were calculated for the 97 diatom associations that were enumerable (diatoms in three collections were too sparse to count). Values for these indexes, along

Table 3. Percent relative abundance, percent frequency (occurrence), and abundance-occurrence index for the 18 most common diatom taxa.

Rank	Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
1	*Nitzschia palea*	6.75	90	607.50
2	*Achnanthes minutissima*	9.53	43	409.79
3	*Navicula cincta* var. *rostrata*	5.62	66	370.92
4	*Nitzschia frustulum*	4.23	69	291.87
5	*N. f.* var. *subsalina*	4.02	54	217.08
6	*Navicula tenelloides*	3.20	62	198.40
7	*Surirella ovata*	2.16	51	110.16
8	*Amphora coffeiformis*	3.79	29	109.91
9	*Diatoma tenue* var. *elongatum*	2.82	38	107.16
10	*Nitzschia acicularis*	2.15	48	103.20
11	*Cyclotella meneghiniana*	2.13	46	97.98
12	*Synedra famelica*	2.77	34	94.18
13	*Navicula cryptocephala*	1.29	62	79.98
14	*N. c.* var. *veneta*	1.49	52	77.48
15	*Nitzschia dissipata*	1.91	39	74.49
16	*Navicula secreta* var. *apiculata*	1.38	49	67.62
17	*Cymbella minuta*	1.78	37	65.86
18	*Nitzschia communis*	1.52	43	65.36

with measured SC values and measured and calculated TDS values, are listed in Appendix D.

Simple correlation coefficients (r) were then computed between SC and each of the two diversity indexes for the 91 sites having both diversity and salinity data. The following correlation coefficients were obtained:

$$r_{DSC} = -0.451$$

$$r_{SDSC} = -0.468$$

Both of these values are significant to the 1 percent level of probability, indicating there is a significant inverse relationship between salinity and diatom diversity in the waters sampled.

Simple correlation coefficients between species relative abundance and SC values were also calculated for the 18 most common diatom taxa listed in Table 3. None of the coefficients obtained (Table 4) proved to be significant, even to the 5 percent level of probability. Two factors might account for this: (i) the relationship may not be linear, and/or (ii) other parameters may be more important in determining relative abundance over the range of salinity values for a given species.

To test the former hypothesis, the percent relative abundance values of two species were plotted as a function of SC. Figure 1 shows that within the salinity ranges of these two species, the relationship is more bell-shaped than linear, with an optimum lying somewhere between the two extremes. Consequently, a significant linear relationship could be expected only on one or both sides of the optimum. Over the entire salinity range, any positive and negative coefficients on either side of the optimum could be expected to cancel one another, thus at least partly explaining the low r values in Table 4.

Maximum, minimum, and mean TDS values for 25 of the more frequently occurring taxa are also listed in Table 4. Extreme TDS values well beyond the normal range of a taxon and represented by only one cell were eliminated from consideration to discount any possible chance occurrence. The maximum and minimum values therefore delineate the normal salinity range for each taxon in the waters that were sampled. The mean TDS value is intended as an estimator of the optimum salinity level for each taxon.

DISCUSSION

Maximum allowable salinity levels in water depend on what the water

Table 4. Mean and range of TDS values and simple correlation coefficients (r_{SC}) for 25 common diatom taxa from waters subject to saline seep in eastern Montana.

Taxon	n	Mean	Range	r_{SC}
Nitzschia dissipata (Nd)	31	922	436 - 2596	-0.020
Cymbella minuta (Cmi)	30	1286	368 - 6410	0.039
Navicula cryptocephala var. veneta (Ncv)	44	1598	436 - 7303	0.135
Achnanthes minutissima (Am)	37	1711	368 - 6642	0.165
Diatoma tenue var. elongatum (Dte)	34	1791	368 -14394	-0.083
Navicula cryptocephala (Nc)	54	1910	332 - 7244	0.174
N. secreta var. apiculata (Nsa)	42	2360	332 -12669	-0.151
Surirella ovata (So)	42	2427	332 - 8094	-0.107
Cyclotella meneghiniana (Cme)	41	2842	368 -16169	-0.179
Pleurosigma delicatulum (Pd)	24	3023	944 -12669	-----
Navicula peregrina (Npe)	23	3660	944 -16849	-----
Synedra famelica (Sfam)	33	3799	596 -14469	0.252
Nitzschia frustulum var. subsalina (Nfs)	50	4124	478 -23819	-0.128
N. apiculata (Nap)	48	4305	368 -42519	-----
N. palea (Np)	82	4560	332 -42519	-0.137
N. acicularis (Nac)	45	4980	596 -42519	0.224
Entomoneis paludosa (Ep)	33	5002	684 -23819	-----
Navicula cincta var. rostrata (Ncr)	61	5119	332 -42519	0.214
Nitzschia frustulum (Nf)	63	5325	332 -42519	-0.022
Synedra fasciculata (Sfas)	26	5332	944 -42519	-----
Navicula pygmaea (Npy)	19	6434	844 -23819	-----
N. tenelloides (Nt)	57	6839	654 -42519	0.283
N. salinarum (Ns)	31	7240	746 -42519	-----
Nitzschia communis (Nco)	40	7530	866 -42519	0.147
Amphora coffeiformis (Ac)	23	11190	1311 -42519	0.224
ALL SAMPLES	91	5245	332 -42519	-----

is to be used for. For human consumption salinity should not exceed 500 mg/l TDS (6). For irrigation it should not exceed 5,000 mg/l TDS (6), although detrimental effects may begin at around 1500 mg/l TDS (30). For stock water for beef cattle it should not exceed 10,000 mg/l TDS (6), although water in excess of 4,000 mg/l TDS may be unsatisfactory (21).

The value of a diatom as a water quality indicator is primarily a function of its ecological amplitude. A taxon found over a broad range of salinity values is not as useful for this purpose as one with a relatively narrow tolerance. To illustrate, the mean and extreme salinity levels of the taxa listed in Table 4 are superimposed over

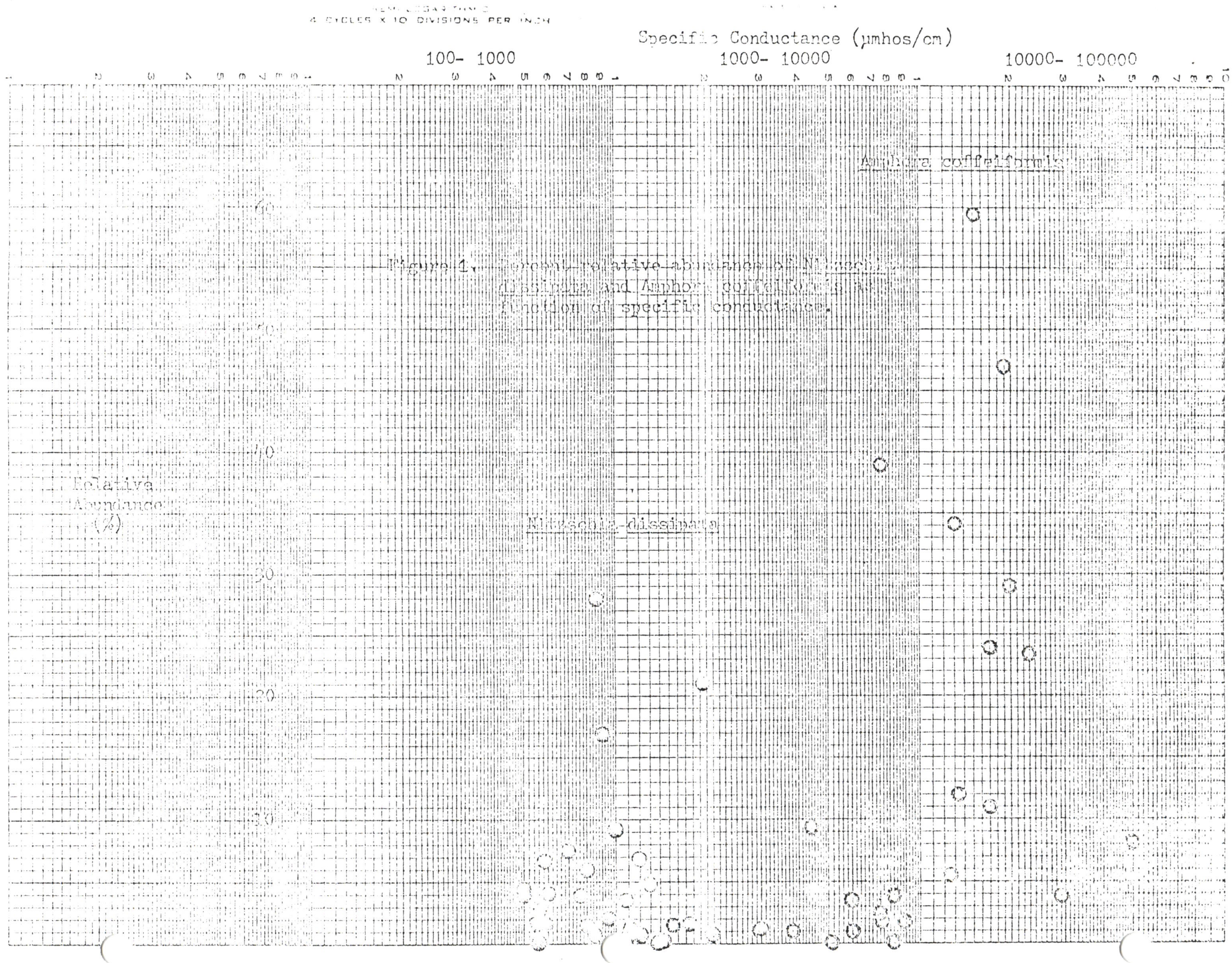

Figure 1. Percent relative abundance of *Nitzschia dissipata* and *Amphora coffeiformis* as a function of specific conductance.

the maximum permissible levels for the water uses discussed above (Figure 2). In making this comparison, a number of points become evident. First, three species are relatively valueless as indicators because of their broad salinity range, which matches the range of TDS for all 91 samples. Second, none of the taxa can be used affirmatively as an indicator of water suitable for human consumption. The most salinity intolerant form--Nitzschia dissipata--indicates water that is suitable for livestock and most irrigation applications. At the other end of the scale, Amphora coffeiformis is indicative of water that is unsuitable for drinking, most irrigation, and probably stock watering as well. In between these two taxa are 23 others with varying salinity ranges and means.

Kolbe (16) devised a halobion spectrum for circumscribing salinity preferences of diatom taxa. Although it was originally intended to apply only to chlorides, it is generally understood to reflect total salt concentration in its present usage. Kolbe's halobion spectrum is presented in Table 5.

Lowe (17), Patrick and Reimer (23, 24), and others have summarized the salinity preferences of a great many diatom taxa from a large number of published reports. Reported salinity preferences for the 25 taxa in Table 4 and Figure 2 are given in Table 6. These decriptions are generally in agreement with salinity reanges and means associated with these taxa in eastern Montana.

The wealth of published information on salt preferences for most common freshwater diatoms offers an excellent opportunity for devising a biological system for rating salinity affects in surface waters. To begin with, the spectral designations in Table 5 could be

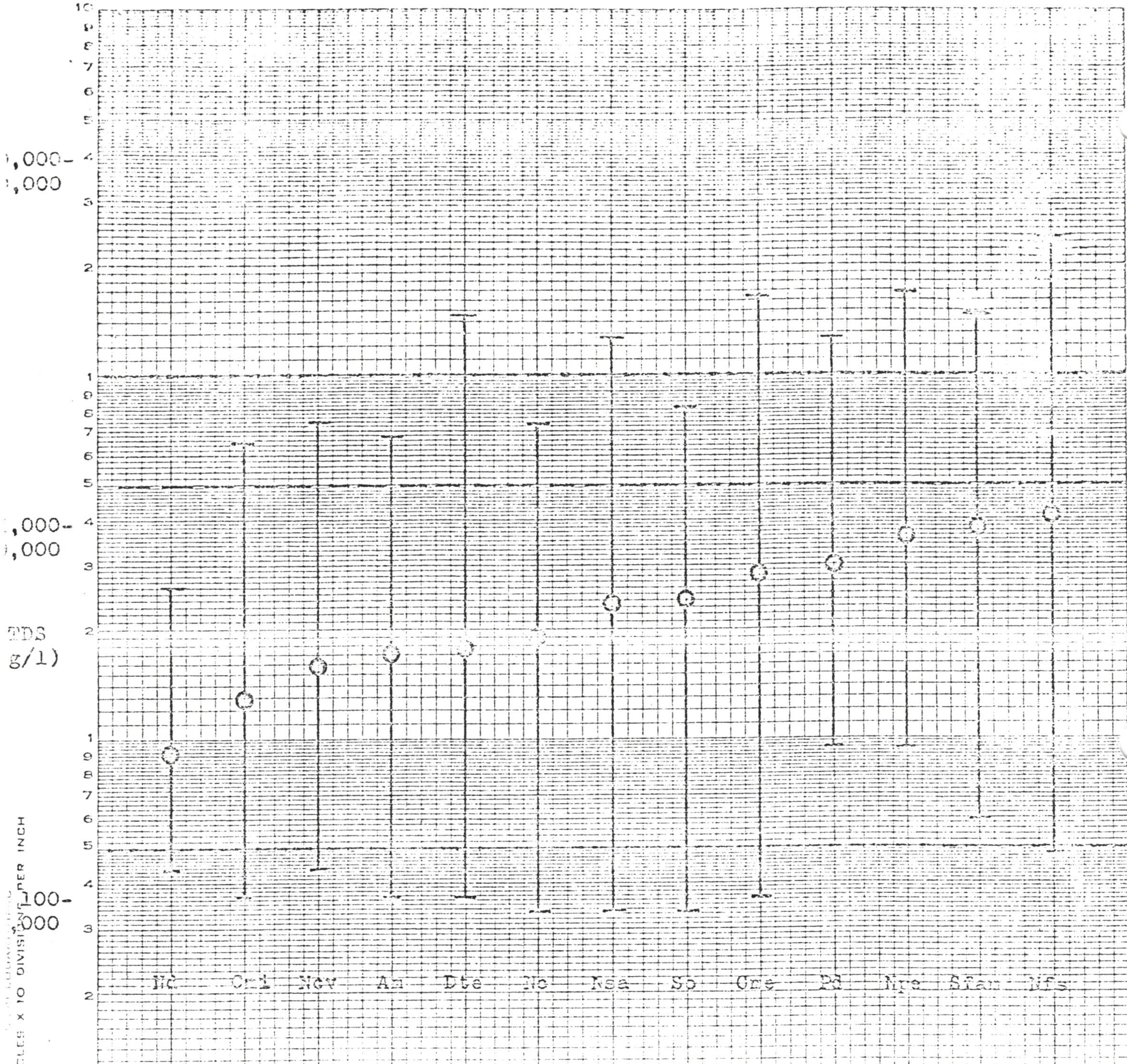

Figure 2. Mean and range of TDS values for 25 common diatom [illegible]

[illegible] Montana

Proposed safe limit for beef cattle (6)

Maximum suggested limit for irrigation (6)

Recommended permissible limit for public water supplies (6)

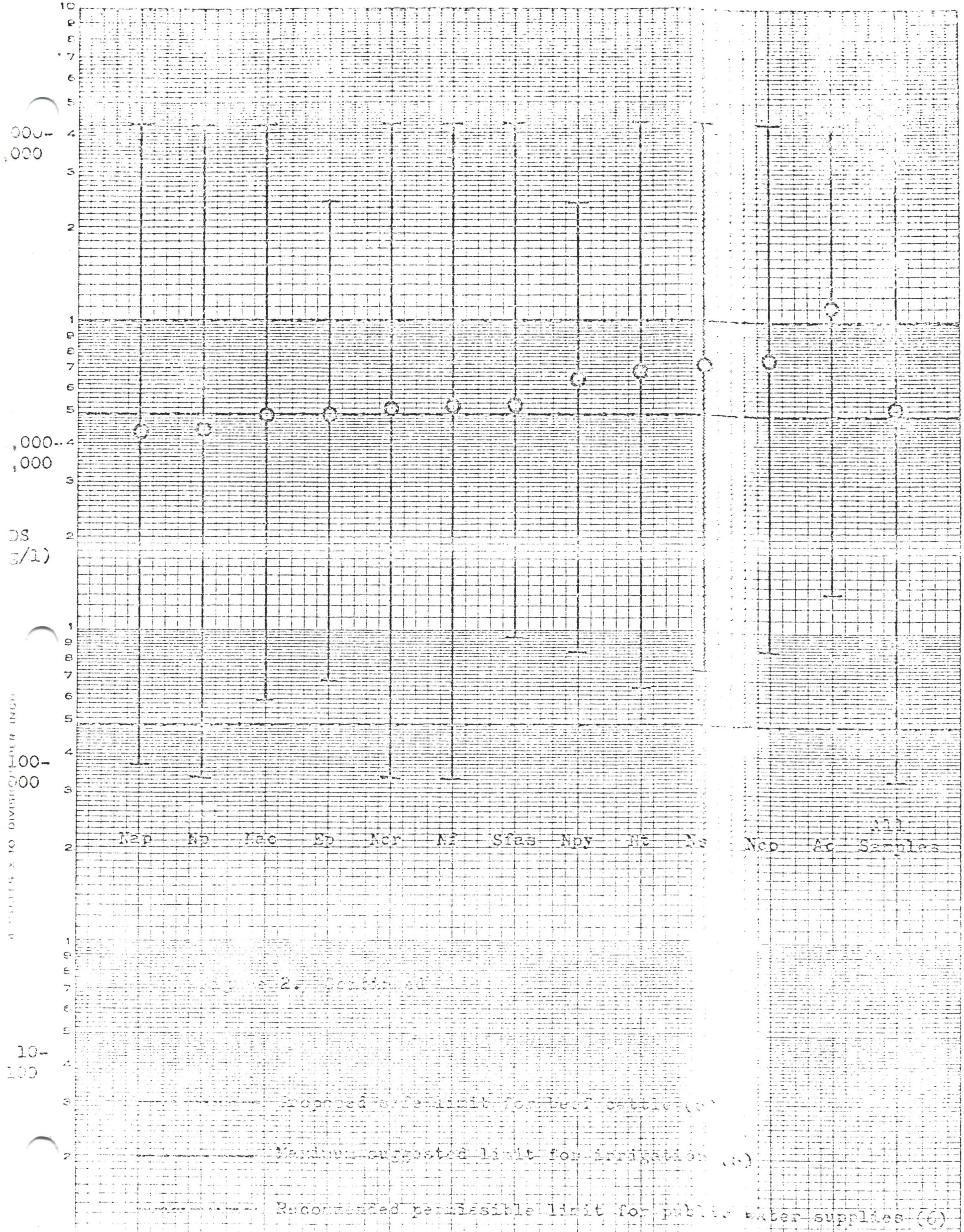

Figure 2. Continued

Table 5. Halobion (salinity) spectrum modified from Kolbe (16) as reported by Lowe (17).

Freshwater (Oligohalobous)	< 500 mg/l TDS
halophobous: does not tolerate small amounts of salt	
indifferent: tolerates small amounts of salt	
halophilous: stimulated by small amounts of salt	
Brackish water (Mesohalobous)	500 - 30,000 mg/l TDS
beta range: 500 - 10,000 mg/l TDS	
alpha range: 10,000 - 30,000 mg/l TDS	
Marine (Euhalobous)	30,000 - 40,000 mg/l TDS
Extra-marine (Polyhalobous)	>40,000 mg/l TDS

Euryhalinous (Euryhalobous): occurs over a broad range of salt concentrations, encompassing two or more large spectral designations.

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scaled as follows:

oligohalohous	1.0
beta-mesohalobous	2.0
alpha-mesohalobous	3.0
euhalobous	4.0
polyhalobous	5.0

Next, a diatom sample is collected from a water in question. The sample is counted and percent relative abundance values are determined for all taxa. Then each taxon is assigned to one of the above spectral designations and weighted according to its relative abundance, which is multiplied by the scaled value of that designation. These products are added and then divided by 100, which puts the final value within range of the scale described above. A rating of less than 2.0 would indicate fresh (oligohalobous) water with TDS less than 500 mg/l. A rating between 2 and 3 would indicate brackish (beta-mesohalobous) water with TDS between 500 and 10,000, and so on.

To further illustrate how this rating system might work, an example is taken from the present survey. Sample 0211A had six species

Table 6. Reported salinity preferences for common diatom taxa from waters subject to saline seep in eastern Montana.

Taxon	Salinity Preference
Nitzschia dissipata	indifferent (17)
Cymbella minuta	indifferent (17), oligohalobous (24)
Navicula cryptocephala var. veneta	indifferent to mesohalobous (17)
	fresh to brackish water (23)
Achnanthes minutissima	indifferent (17)
	oligohalobous (23)
Diatoma tenue var. elongatum	halophilous (17)
	fresh to slightly brackish (23)
Navicula cryptocephala	indifferent (17)
	fresh to slightly brackish (23)
N. secreta var. apiculata	fresh water of high mineral content (23)
Surirella ovata	indifferent (17)
Cyclotella meneghiniana	halophilous (17)
Pleurosigma delicatulum	fresh to brackish (23)
Navicula peregrina	meso halobous (17)
	brackish (23)
Synedra famelica	high mineral content (23)
Nitzschia frustulum var. subsalina	weakly saline water (10)
N. apiculata	mesohalobous (17)
N. palea	indifferent (17)
N. acicularis	indifferent (17)
Entomoneis paludosa	mesohalobous (17)
	moderately high conductivity (24)
Navicula cincta var. rostrata	total hardness= 376 mg/l (27)
Nitzschia frustulum	halophilous to indifferent and euryhalobous (17)
Synedra fasciculata	high conductivity, slightly brackish (23)
Navicula pygmaea	hard fresh to brackish (23)
N. tenelloides	aerophil (23)
N. salinarum	hard fresh to brackish (23)
Nitzschia communis	indifferent (17)
Amphora coffeiformis	mesohalobous (17)
	high conductivity (24)

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distributed as follows:

Navicula pygmaea	43.9%	x 2.0	= 87.8
N. cincta var. rostrata	10.7	x 2.0	= 21.4
N. protracta	5.0	x 2.0	= 10.0
N. odiosa	0.8	x 2.0	= 1.6
Amphora coffeiformis	38.8	x 3.0	=116.4
Navicula tenelloides	0.8	x 3.0	= 2.4
	100.0		239.6

The first four listed taxa are considered beta-mesohalobous and should be scaled with a value of 2.0 as indicated. The last two taxa may be considered alpha-mesohalobous and should be scaled with a value of 3.0.

The sum of products divided by 100 gives a biological salinity rating of 2.4 or somewhere about midway between 500 and 10,000 mg/l TDS. The TDS value at this site, estimated from SC, was 6394 mg/l.

The value of a system such as this, however, is not its ability to estimate TDS. Even assuming it is reasonably accurate at doing so, it would be much simpler to measure TDS directly. Its real value lies in its numerical representation of the collective response of a significant portion of the biological community to a given category of stress applied over a period of time. After refinement and testing, such a scaling system could be used for monitoring the biological response to surface water salinization in eastern Montana.

CONCLUSIONS AND RECOMMENDATIONS

This survey has established the potential of algal toxicity to livestock and wildlife in one quarter of the waters sampled. However, for a variety of reasons repeated below, no statement can be made regarding the immediate danger to such animals posed by possibly toxic algae consumed in waters subject to saline seep in eastern Montana:

1. Most of the samples were collected in the spring of the year, a time when blue-green algae do not reach their full growth potential.
2. Water blooms, responsible for most cases of algal toxicity, ordinarily develop only in the plankton of standing waters. Such waters (reservoirs) are also the most dependable water supplies for livestock and wildlife. Standing waters accounted for only 8 of the 100 collections and the plankton community was not sampled in any of these.
3. Taxonomic identification does not confirm the presence or absence of a toxic algae problem. Different strains of the same species, undistinguishable under the microscope, can form blooms that are deadly or merely obnoxious.

4. About 85 percent of the samples were collected by individuals unfamiliar with algal growth forms and sampling techniques. Although unlikely, these individuals may have overlooked concentrations or blooms or potentially toxic algae.

Nevertheless, the potential is significant enough to warrant an effort to educate livestock producers of the problem. Ranchers should be warned to refrain from watering their livestock with waters having a green "pea soup" appearance, which may develop from late summer into autumn. Ranchers, county extension agents, and other local agricultural people should be advised to send samples of such waters to the Water Quality Bureau for analysis. If the sample contains a potentially toxic species in concentrations typical of a bloom, the water should be tested in laboratory animals following standard clinical procedures. Ranchers should also be advised to submit for analysis samples of any waters suspected of causing death or sickness in livestock regardless of the water's appearance. All samples should be submitted as soon as possible after toxic effects become apparent or a bloom appears. A pint or quart jar of water scooped from near shore would be a sufficient sample for diagnosis of a toxic algae problem.

A statistically significant relationship exists between high salinity levels and low biological diversity in the waters sampled. More subtle changes in species relative abundance and gradual replacement of less tolerant species also accompanied salinization. The diatom component of the periphyton community may prove to be a sensitive monitor of the biological effects of salinity increases in surface waters of eastern Montana. Most of the species encountered are widely distributed and their salinity preferences have been well documented.

Enough information on the autecology of various species exists for constructing a salinity impact rating system based on salinity preferences and species relative abundance.

This consultant proposes establishing a biological salinity impact monitoring network composed of 10 to 20 stations on a few key waterways in eastern Montana. Existing water quality monitoring stations of the USGS or Water Quality Bureau could be adopted and new stations set up where there is significant evidence of increasing salinization. In addition to the standard physical and chemical water quality parameters, the network would emphasize periodic measurements of diatom community response, including species diversity, species relative abundance, and periphyton biomass accrual on artificial substrates.

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Appendix A. Sample locations and dates.

Number	Site	Date
0016A	Big Spring Creek, N. of Lewistown, 15N.18E.5DA	9-12-74
0017A	Musselshell R., above Harlowton	9-13-74
*0018A	American Fk., E. of Harlowton on gravel rd., 07N.15E.5CB	9-13-74
0019A	Flatwillow Cr., @ FAS 500, 14N.30E.33CB	9-9-74
0020A	Judith R., @ Highway 87	10-16-74
0021A	Judith R., Headwaters near Utica, gravel rd. SE of Utica @ bridge, 14N.13E.28BBB	10-17-74
0022A	Arrow Cr. @ Highway 230, 19N.12E.13BA	10-16-74
0023A	Warm Spring Cr. @ Highway 235, 17N.17E.17AD	10-16-74
0024A	Cottonwood Cr. near Lewistown @ Highway 87. 15N.17E.22BA	10-16-74
0025A	Judith R., Middle Fk., S. of Utica 3 mi. 14N.12E.35BD	10-17-74
0037A	Judith R. at mouth near Highway 236, 23N.16E.25BA	11-7-74
0038A	Missouri R. @ PN Ferry, 23N.16E.25BA	11-7-74
0039A	Little Careless Cr. Gravel Rd. near Harlowton, Musselshell Basin, Wheatland Co., 10N.18E.09AA	11-8-74
0040A	Judith R. between Hobson & Utica (Hwy 239), Judith Basin Co. 14N.14E.10BA	11-7-74
0041A	Painted Robe Cr. SE of Lavina near mouth (1 mi. S., 5 mi. E.) Golden Valley Co. 23E.6N.15	11-21-74
0042A	Big Elk Cr., So. of Two Dot (1st farmhouse), Wheatland Co., 13E.8N.26	11-21-74
0043A	Musselshell R. @ Melstone	11-20-74
0109A	Wolf Cr. @ Denton	9-26-75
0110A	Judith R. @ Utica	9-26-75
* 0111A	Seep 1 mi. W. of Judith in big sag, Fergus Co., 22N.16E.10CC	9-24-75
** 0112A	Ackley Lake., SW of Hobson	9-26-75
0113A	Arrow Cr. @ Mouth, 15E.23N.	9-24-75
0114A	Sage Cr., Judith Basin Co., 16N14E.bcc	9-24-75
*0137A	Calf Cr. Highway 200 near Sand Springs	3-17-76
0138A	Cow Cr. @ Hwy 13 near Circle	3-16-76
0139A	Big Dry Cr. @ Hwy 200, Jordan	3-17-76
0140A	Redwater R. @ Circle	3-16-76
0141A	Yellowstone Co., N. of Acton near power line 03N.24E.11CC	4-9-76
*0142A	Yellowstone Co., 03N.24E.35BC	4-9-76
0143A	Teton R. N. of Ft. Benton on Hwy 233	4-23-76
0144A	Marias R. @ confluence w/ Teton R. @ Loma	4-23-76
0145A	Big Sandy Cr., 3 mi. E. of Big Sandy., S. off Hwy on gravel rd. $\frac{1}{2}$ mi.	4-23-76
0146A	Milk R., 13 mi. E. of Havre @ Lohman under bridge	4-24-76
*0147A	Threemile Cr., So. of Harlem on Hwy 376	4-24-76
*0148A	Pylan Cr. @ 4 mi. Corner E. of Rapelje, 03N.20E.36AA.	4-21-76
0149A	Seep by Windmill N. of BN tracks, Stillwater Co., 02N.21E.11DD	4-21-76

Appendix A., Continued.

Reference Number	Site	Date
0150A	Seep $\frac{1}{4}$ mi. N. of farm buildings, Stillwater Co., 01N.21E.02BC	4-22-76
0151A	Luke Cr. behind Wilcox house, Stillwater Co., 03N.21E.18BD	4-21-76
*0152A	Hopex Cr. @ culvert, Stillwater Co., 01N.21E.10AB	4-22-76
0153A	Seep @ crossroads E. of Bottle Butte, Stillwater Co. 02N.21E.31BBB	4-22-76
0154A	Seep 9 mi. E. of farm buildings (sample No. 11), 01N.21E.08AA	4-22-76
*0155A	White Bear Cr. So. of Harlem on Hwy 376	4-24-76
0156A	Peoples Cr. @ Hwy 376 So. of Harlem	4-24-76
0157A	Missouri R. @ James Kipp State Rec. Area., U.S. 191	4-24-76
0159A	Small pond S. of Scobey in saline seep area	5-25-76
*0168A	Deer Cr. near Decker, Big Horn Co.	6-10-76
0169A	Lone Tree Cr., South Fk., Richland Co., 23N.57E.09DDD	6-15-76
*0170A	Tributary of E. Redwater Cr., Richland Co., 23N.53E.36BBC	6-15-76
*0171A	Hardscrabble Cr., Richland Co., 26N.55E.01DBB	6-15-76
0172A	Eagle Cr., Daniels Co., 35N.50E.27CBB	6-17-76
*0173A	Plentywood Cr. @ bridge, Sheridan Co., 35N.54E.16CDA	6-17-76
0174A	Redstone Cr. @ Hwy 5, Sheridan Co., 35N.52E.09BAD	6-17-76
0175A	Big Muddy Cr. @ road, Sheridan Co., 32N.55E.27BAA	6-16-76
*0176A	N. Fk. E. Redwater Cr., Richland Co., 24N.53E.25BBB	6-15-76
0177A	Antelope Cr., Sheridan Co., 34N. 56E.10DDD	6-16-76
*0178A	Charlie Cr., Richland Co., 26N.54E.15BBB	6-15-76
*0179A	Jeffrey Cr., Richland Co., 24N.53E.36BB	6-15-76
0180A	Seep 3 mi. E. of Culbertson, Roosevelt Co., 28N.56E.27ADD	6-16-76
0181A	First Hay Cr. @ bridge, Richland Co., 24N.58E.16DDB	6-15-76
0182A	Seep E. of Hwy 16, Richland Co., 25N. 58E.32DDD	6-17-76
*0183A	First Hay Cr., N. Fk., Richland Co., 25N.58E.31DDD	6-15-76
0184A	Little Muddy Cr., Roosevelt Co., 28N.59E.28DDC	6-16-76
0185A	Red Bank Cr., Roosevelt Co., 28N.59E.31AAC	6-16-76
0186A	Butte Cr. @ bridge, Daniels Co., 35N.47E.12ADD	6-17-76
0187A	Marron Cr., Sheridan Co., 35N.55E.21CDD	6-16-76
0188A	Sheep Cr. @ Hwy 16, Roosevelt Co., 30N.56E.30BBB	6-16-76
0189A	Lost Cr. @ Hwy 16, Roosevelt Co., 30N.56E.7BBB	6-16-76
0190A	ponds @ R.R. crossing (Bainville), Roosevelt Co., 28N.58E.20DDD	6-16-76
0191A	Sand Cr., Roosevelt Co., 30N.58E.14DCC	6-16-76
0192A	McCoy Cr. @ Hwy 5, Sheridan Co., 35N.54E.14BBC	6-17-76
0193A	Crail Cr., Yellowstone Co., 1N.23E.05DDD	6-24-76
0194A	No Name Cr., Yellowstone Co., 1N.23E.03DDD	6-24-76
*0195A	Stream seep, Yellowstone Co., 4N.25E.09CDC	6-25-76
0196A	"No. 21", Stillwater Co., 1N.23E.06DD	6-24-76
0197A	Cove Cr., Yellowstone Co., 1N.24E.15DCA	6-24-76
0198A	Creek, Yellowstone Co., 2N.24E.32CBB	6-24-76
*0199A	Small puddle, Yellowstone Co., 4N.25E.06CD	6-25-76

Appendix A., Continued.

Reference Number	Site	Date
0200A	Carla Cr., Stillwater Co., 1N.23E.06BC	6-24-76
0201A	N. Fk. Fivemile Cr., Yellowstone C., 2N.25E.19CAB	6-24-76
0202A	Chouteau Co., 24N.9E.36	8-5-76
*0203A	Chouteau Co., 21N.12E.34BDD	8-7-76
*0204A	Bird Coulee, Chouteau Co., 23N.8E.19BDD	8-8-76
*0205A	Crawford Ranch, Chouteau Co., 23N.6E.18	N.D.
0206A	Clear Cr., BlaineCo. Vercruyssen property, 31N.18E.20	7-8-76
0207A	Bullwhacker Coulee, Blaine Co., 26N.19E.35	7-8-76
* **0208A	Reservoir, Blaine Co., 34N.21E.31C	7-9-76
*0209A	Saline seep area, Valley Co., 23N.37E.12DAA	7-26-76
0210A	Pond in seep area, Phillips Co., 27N.31E.28	7-23-76
0211A	Phillips Co., 24N.24E.22	7-25-76
0212A	Valley Co., 25N.36E.5BBD	7-27-76
0213A	Natural saline seep, Valley Co., 24N.38E.14ADD	7-26-76
0214A	Whitewater Cr. under bridge, Phillips Co., 36N.30E.9	7-21-76
0215A	Rock Cr., Valley Co., 35N.36E.33DC	7-27-76
0219A	Reservoir, Cascade Co., 19N.02W.08BD	8-25-76
*0220A	Pond, Teton Co., 23N.3W.33BBB	8-28-76
0221A	Fergus Co., 15N.22E.09B	9-10-76
0222A	Crown Butte Cr., Cascade Co., 20N.02W.25CA	8-27-76
0223A	Petroleum Co., 13N.26E.2CDC	9-13-76
0224A	Fergus Co., 19N.22E.05BBD	9-13-76
0225A	Cascade Co., 17N.02E.17C	8-28-76

* Waters containing genera of blue-green algae that include species suspected of producing strains toxic to livestock or wildlife.

**Waters containing a species of blue-green algae (*Aphanizomenon flos-aquae*) suspected of producing strains that are toxic to livestock or wildlife.

Appendix B. Genera of non-diatom algae found in the periphyton of surface waters suspected to be influenced by saline seep in eastern Montana.

Chlorophyta (green algae) 25 Genera

Ankistrodesmus
Bulbochaete
Chara
Chlamydomonas
Chlorococcum
Chlorogonium
Cladophora
Closterium
Cosmarium
Enteromorpha
Gloeocystis
Hormidium
Mougeotia
Oedogonium
Pediastrum
Planktosphaeria
Platymonas
Rhizoclonium
Scenedesmus
Schroederia
Sphaerocystis
Spirogyra
Stigeoclonium
Ulothrix
Zgynema

Euglenophyta (euglenoid algae) 3 Genera

Euglena
Phacus
Westella

Chrysophyta (golden-brown algae) 8 Genera

Characiopsis
Chrysochromulina
Chrysococcus
Diatoms
Dinobryon
Ochromonas
Tribonema
Vaucheria

Cyanophyta (blue-green algae) 19 Genera

*Anabaena
*Aphanizomenon
Arthrospira
Calothrix
Chroococcus
*Gomphosphaeria
Heterohormogonium

Appendix B. (Continued)

<u>Cyanophyta</u> (Continued)
- Hyella
- *Lyngbya
- Merismopedia
- *Nodularia
- *Nostoc
- Oscillatoria
- Phormidium
- Rivularia
- Spirulina
- Stichosiphon
- Synechocystis
- Tolypothrix

<u>Rhodophyta</u> (red algae) 1 Genus
- Audouinella

<u>Cryptophyceae</u> (algae of uncertain position) 1 Genus
- Rhodomonas

*Genera containing species of blue-green algae suspected of producing strains that are toxic to livestock or wildlife.

Appendix C. Percent relative abundance, percent frequency (occurrence), and abundance-occurence index for diatom taxa identified from surface waters suspected to be influenced by saline seep.

Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
Achnanthes affinis	0.37	3	1.11
A. clevei	0.01	1	0.01
A. deflexa	0.14	8	1.12
A. flexella	t	2	----
A. hauckiana var. rostrata	0.01	2	0.02
A. lanceolata	0.24	24	5.76
A. lapponica var. ninckei	t	1	----
A. linearis	0.11	9	0.99
A. linearis f. curta	0.01	2	0.02
A. minutissima	9.53	43	409.79
A. sp.	0.05	5	0.25
Amphipleura pellucida	0.34	26	8.84
Amphora coffeiformis	3.79	29	109.91
A. ovalis	0.03	8	0.24
A. ovalis var. affinis	0.01	8	0.08
A. ovalis var. pediculus	0.38	19	7.22
A. veneta	0.42	14	5.88
A. sp.	t	1	----
Anomoeoneis costata	0.01	4	0.04
A. sphaerophora	t	2	----
A. vitrea	0.07	5	0.35
A. sp.	t	1	----
Asterionella formosa	0.01	3	0.03
Bacillaria paradoxa	0.05	5	0.25
Caloneis amphisbaena	0.01	10	0.10
C. bacillum	0.11	11	1.21
C. hyalina	0.05	1	0.05
C. ventricosa var. alpina	t	1	----
C. ventricosa var. minuta	t	2	----
C. ventricosa var. truncatula	0.07	7	0.49
C. sp.	0.02	3	0.06
Chaetoceros elmorei	0.21	2	0.42
Cocconeis pediculus	2.19	19	41.61
C. placentula	0.65	29	18.85
C. placentula var. euglypta	1.09	13	14.17
C. placentula var. lineata	0.03	4	0.12
Cyclotella glomerata	0.01	3	0.03
C. kutzingiana	0.28	6	1.68
C. meneghiniana	2.13	46	97.98
C. sp.	0.01	3	0.03
Cylindrotheca gracilis	0.12	15	1.80
Cymatopleura solea	0.01	13	0.13
Cymbella affinis	0.80	22	17.60
C. amphicephala	0.01	5	0.05
C. cistula	0.01	9	0.09
C. cymbiformis var. nonpunctata	t	1	----
C. delicatula	0.22	5	1.10

t = trace

Appendix C. (Continued)

Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
Cymbella lunata	0.01	3	0.03
C. mexicana	0.01	5	0.05
C. microcephala	1.32	23	30.36
C. minuta	1.78	37	65.86
C. muelleri	0.01	2	0.02
C. parva	0.03	2	0.06
C. prostrata	0.01	4	0.04
C. pusilla	0.74	20	14.80
C. rupicola	0.03	3	0.09
C. sinuata	0.16	10	1.60
C. triangulum	0.01	1	0.01
C. tumida	t	2	----
C. sp.	0.01	3	0.03
Denticula elegans	0.07	7	0.49
D. subtilis	0.01	8	0.08
D. sp.	0.05	12	0.60
Diatoma tenue	t	1	----
D. tenue var. elongatum	2.82	38	107.16
D. vulgare	0.34	22	7.48
D. vulgare var. breve	0.01	2	0.02
D. vulgare var. mesodon	t	1	----
D. sp.	0.01	1	0.01
Diploneis elliptica	0.03	1	0.03
D. puella	0.07	8	0.56
D. sp.	0.02	6	0.12
Entomoneis ornata	0.17	17	2.89
E. paludosa	0,67	34	22.78
E. robusta	t	1	----
E. sp.	t	4	----
Epithemia adnata var. saxonica	0.09	3	0.27
E. argus	0.01	1	0.01
E. sorex	1.13	11	12.43
E. turgida	0.03	9	0.27
E. sp.	0.03	7	0.21
Eunotia curvata	t	2	----
Fragilaria brevistriata var. inflata	t	1	----
F. brevistriata var. ?	t	1	----
F. capucina	0.05	2	0.10
F. capucina var. mesolepta	1.16	2	2.32
F. construens	0.03	6	0.18
F. construens var. subsalina	0.01	1	0.01
F. construens var. venter	0.03	8	0.24
F. crotonensis	0.18	6	1.08
F. leptostauron	t	1	----
F. vaucheriae	1.01	33	33.33
F. sp.	0.11	7	0.77
Gomphoneis herculeana	0.01	1	0.01
Gomphonema acuminatum	0.01	2	0.02

t = trace

Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
Gomphonema acuminatum var. ?	t	1	----
G. affine	0.02	3	0.06
G. angustatum	0.32	26	8.32
G. angustatum var. productum	0.02	1	0.02
G. angustatum var. ?	t	1	----
G. bohemicum	0.07	6	0.42
G. consector	0.01	1	0.01
G. dichotomum	0.03	4	0.12
G. gracile	t	1	----
G. intricatum	0.09	12	1.08
G. olivaceum	1.47	23	33.81
G. olivaceum var. calcarea	0.05	7	0.35
G. parvulum	0.49	39	19.11
G. tergestinum	0.01	1	0.01
G. truncatum	0.01	4	0.04
G. sp.	0.02	10	0.20
Gyrosigma acuminatum	0.01	5	0.05
G. attenuatum	0.01	1	0.01
G. exilis	0.01	1	0.01
G. peisonis	0.21	17	3.57
G. spencerii	0.05	16	0.80
G. spencerii var. curvula	0.01	2	0.02
G. sp.	0.01	7	0.07
Hantzschia amphioxys	0.07	23	1.61
H. amphioxys var. major	t	1	----
Mastogloia elliptica var. danseii	0.01	5	0.05
M. smithii	0.17	2	0.34
M. smithii var. lacustris	t	2	----
M. sp.	0.01	4	0.04
Melosira granulata var. angustissima	t	2	----
M. varians	t	4	----
M. sp.	0.03	3	0.09
Meridion circulare	0.02	7	0.14
Navicula accomoda	0.09	8	0.72
N. arvensis	0.06	7	0.42
N. atomus	0.72	18	12.96
N. auriculata	0.01	1	0.01
N. biconica	t	1	----
N. capitata	0.01	2	0.02
N. capitata var. hungarica	0.13	14	1.82
N. cincta	0.66	15	9.90
N. cincta var. heufleri	t	1	----
N. cincta var. rostrata	5.62	66	370.92
N. circumtexta	0.05	12	0.60
N. cryptocephala	1.29	62	79.98
N. cryptocephala f. terrestris	0.16	1	0.16
N. cryptocephala var. exilis	t	2	----
N. cryptocephala var. veneta	1.49	52	77.48
N. cryptocephala var. ?	0.16	3	0.48

t = trace

Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
Navicula cuspidata	0.02	14	0.28
N. cuspidata var. obtusa	0.01	1	0.01
N. gottlandica	0.01	2	0.02
N. graciloides	0.07	14	0.98
N. halophila	0.02	7	0.14
N. halophila var. tenuirostris	0.01	2	0.02
N. heufleri	0.05	7	0.35
N. heufleri var. leptocephala	0.18	15	2.70
N. integra	t	1	----
N. jaagii	0.16	18	2.88
N. laevissima	0.02	5	0.10
N. lanceolata	0.01	6	0.06
N. menisculus var. upsaliensis	0.03	1	0.03
N. minima	0.01	2	0.02
N. minnewaukonensis	0.03	2	0.06
N. minuscula	0.03	3	0.09
N. mutica	0.03	11	0.33
N. mutica var. undulata	0.01	5	0.05
N. mutica var. ?	0.01	2	0.02
N. oblonga	0.01	2	0.02
N. odiosa	0.01	2	0.02
N. pelliculosa	0.01	1	0.01
N. peregrina	0.05	24	1.20
N. protracta	0.04	1	0.04
N. pupula	0.01	7	0.07
N. pupula var. capitata	t	1	----
N. pygmaea	0.56	20	11.20
N. radiosa	0.01	7	0.07
N. radiosa var. parva	0.03	8	0.24
N. rhynchocephala	0.34	4	1.36
N. rhynchocephala var. germainii	0.26	2	0.52
N. salinarum	1.22	33	40.26
N. salinarum var. intermedia	t	1	----
N. secreta var. apiculata	1.38	49	67.62
N. simplex	0.22	8	1.76
N. symmetrica	0.01	2	0.02
N. tenelloides	3.20	62	198.40
N. tenera	t	2	----
N. tripunctata	0.83	38	31.54
N. tripunctata var. schizonemoides	0.01	2	0.02
N. ventralis var. chilensis	t	1	----
N. viridula	0.01	5	0.05
N. viridula var. avenacea	0.82	13	10.66
N. viridula var. rostellata	0.03	4	0.12
N. sp.	0.74	46	34.04
Neidium affine var. amphirhynchus	0.01	2	0.02
N. binode	0.01	1	0.01
N. bisulcatum	0.01	1	0.01
N. sp.	t	2	----

t = trace

Appendix C. (Continued)

Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
Nitzschia acicularis	2.15	48	103.20
N. acuta	0.04	5	0.20
N. amphibia	0.18	20	3.60
N. angustata	t	1	----
N. angustata var. acuta	0.01	2	0.02
N. apiculata	0.43	54	23.22
N. bulnhelniana	0.02	1	0.02
N. capitellata	0.05	5	0.25
N. clausii	0.03	3	0.09
N. closterium	t	1	----
N. communis	1.52	43	65.36
N. denticula	0.01	3	0.03
N. dissipata	1.91	39	74.49
N. epiphytica	0.08	8	0.64
N. epithemioides	t	1	----
N. fasciculata	t	3	----
N. filiformis	0.32	14	4.48
N. fonticola	0.07	8	0.56
N. frustulum	4.23	69	291.87
N. frustulum var. subsalina	4.02	54	217.08
N. frustulum var. ?	t	1	----
N. gandersheimiensis	t	1	----
N. gracilis	0.85	30	25.50
N. hantzschiana	0.01	2	0.02
N. hungarica	0.13	30	3.90
N. ignorata	0.60	3	1.80
N. kutzingiana	0.33	8	2.64
N. linearis	0.12	18	2.16
N. longissima var. reversa	0.56	16	8.96
N. lorenziana	0.01	1	0.01
N. lorenziana var. subtilis	0.01	2	0.02
N. microcephala	0.12	12	1.44
N. obtusa	0.09	6	0.54
N. ovalis	0.95	32	30.40
N. palea	6.75	90	607.50
N. paleacea	0.90	28	25.20
N. recta	0.07	12	0.84
N. romana	0.07	15	1.05
N. sigma	0.07	14	0.98
N. sigmoidea	0.03	16	0.48
N. stagnorum	t	3	----
N. sublinearis	0.04	3	0.12
N. tryblionella	0.01	9	0.09
N. tryblionella var. debilis	0.03	4	0.12
N. tryblionella var. levidensis	t	1	----
N. tryblionella var. victoriae	t	1	----
N. tryblionella var. ?	t	1	----
N. valdestriata	0.03	2	0.06
N. vermicularis	0.01	2	0.02

t = trace

Taxon	Abundance (%)	Frequency (%)	Abundance-Occurrence (max.=10,000)
Nitzschia vitrea	t	3	----
N. vitrea var. salinarium	0.06	12	0.72
N. vivax	t	1	----
N. vivax var. ?	0.01	1	0.01
N. sp.	0.09	17	1.53
Pinnularia borealis	0.01	5	0.05
P. leptosoma	t	1	----
P. molaris	0.01	8	0.08
P. viridis	t	1	----
P. sp.	0.03	9	0.27
Pleurosigma delicatulum	0.26	24	6.24
P. sp.	t	1	----
Rhoicosphenia curvata	1.03	33	33.99
Rhopalodia gibba	0.11	28	3.08
R. gibba var. ventricosa	0.01	2	0.02
R. gibberula	0.01	3	0.03
R. musculus	0.05	11	0.55
Stauroneis smithii	0.01	2	0.02
Stephanodiscus astraea	t	1	----
S. dubius	0.01	1	0.01
S. minutus	0.62	17	10.54
Surirella angustata	0.09	14	1.26
S. biseriata var. bifrons	t	1	----
S. brightwellii	0.19	2	0.38
S. iowensis	0.03	13	0.39
S. ovalis	0.01	5	0.05
S. ovata	2.16	51	110.16
S. ovata var. pinnata	0.01	4	0.04
S. spiralis	0.01	5	0.05
S. striatula	t	3	----
Synedra acus	0.07	8	0.56
S. affinis	t	1	----
S. delicatissima	t	3	----
S. famelica	2.77	34	94.18
S. famelica var. ?	1.02	1	1.02
S. fasciculata	0.94	30	28.20
S. fasciculata var. ?	0.28	1	0.28
S. minuscula	0.49	4	1.96
S. parasitica	t	1	----
S. pulchella	0.13	8	1.04
S. pulchella var. lacerata	t	1	----
S. radians	0.07	10	0.70
S. rumpens	0.49	9	4.41
S. ulna	1.22	33	40.26
S. ulna var. amphirhynchus	t	1	----
S. ulna var. contracta	0.06	7	0.42
S. ulna var danica	0.01	1	0.01
S. sp.	0.03	6	0.18
Thalassiosira fluviatilis	0.49	15	7.35

t = trace

Appendix D. Margalef diversity (D), Simpson diversity (SD), total dissolved solids (TDS), and specific conductance (SC) at the 100 sites sampled.

Sample No.	D	SD	TDS	SC
0016A	4.94	.842	478	600
0017A	4.46	.845	983	1192
0018A	5.91	.885	368	502
0019A	6.17	.886	2596	3006
0020A	5.18	.869	451	552
0021A	2.79	.806	421	536
0022A	5.51	.866	1722	1910
0023A	3.86	.812	693	1071
0024A	4.04	.729	457	559
0025A	2.59	.831	420	529
0037A	3.91	.882	800	989
0038A	5.17	.884	691	864
0039A	5.37	.876	628	706
0040A	5.16	.854	450	560
0041A	3.59	.648	4672	5270
0042A	5.76	.862	615	760
0043A	----	---	1758	2158
0109A	4.24	.707	1718*	2092*
0110A	2.59	.559	458	578
0111A	2.26	.719	14469+	17000#
0112A	4.78	.748	---	---
0113A	0.50	.020	3210*	3390*
0114A	2.41	.738	16169+	19000#
0137A	----	---	1031+	1190
0138A	3.53	.739	874	1190
0139A	2.90	.726	1100+	1272
0140A	2.48	.709	2097+	2445
0141A	3.61	.795	3452	4184
0142A	1.46	.262	2914	3486
0143A	3.62	.678	654*	795*
0144A	3.65	.812	467*	579*
0145A	3.26	.840	699+	800*
0146A	2.12	.557	436+	490*
0147A	4.87	.814	---	---
0148A	3.54	.818	12669	12000
0149A	2.23	.786	7244+	8500
0150A	2.09	.677	7789	8800
0151A	1.28	.536	18407	23000
0152A	3.06	.848	2999	3347
0153A	3.37	.862	14394	13500
0154A	2.65	.725	7303	7770
0155A	4.40	.849	---	---
0156A	3.60	.870	784+	900*
0157A	3.97	.722	596+	679*
0159A	2.68	.793	3106	3550
0168A	5.56	.892	5075*	5380*
0169A	4.16	.856	1201+	1391
0170A	3.30	.619	7400	8210

Appendix D. Continued.

Sample No.	D	SD	TDS	SC
0171A	5.12	.900	3206+	3749
0172A	3.93	.807	866	1107
0173A	5.51	.880	853	1704
0174A	4.68	.902	1942	2315
0175A	6.65	.884	684	846
0176A	4.30	.891	3630	4469
0177A	----	---	306	452
0178A	4.55	.870	4534	5017
0179A	1.28	.741	7346	8220
0180A	4.88	.863	755	963
0181A	5.64	.902	844	1116
0182A	1.91	.700	6798	7390
0183A	4.42	.896	2343	2733
0184A	4.54	.788	1152	1380
0185A	4.57	.846	2253	2407
0186A	7.26	.872	912	1160
0187A	5.46	.915	746	956
0188A	6.34	.901	899	1186
0189A	1.89	.350	6410*	5910*
0190A	1.65	.268	2148	2297
0191A	4.58	.894	1166	1417
0192A	6.71	.886	944+	1088
0193A	5.49	.890	3454	4247
0194A	5.15	.915	3613	4507
0195A	3.50	.828	---	---
0196A	2.24	.694	1314	1736
0197A	3.15	.690	3028	3628
0198A	2.31	.762	1401+	1989
0199A	3.70	.871	5041	5760
0200A	4.02	.865	1262	1627
0201A	2.33	.481	6642	7290
0202A	3.19	.665	5119+	6000#
0203A	1.29	.515	12769+	15000#
0204A	1.64	.342	6394+	7500#
0205A	1.46	.601	---	---
0206A	6.13	.936	---	---
0207A	2.90	.768	7074+	8300#
0208A	4.53	.766	332+	368#
0209A	3.05	.724	23819+	28000#
0210A	2.54	.588	3343+	3910#
0211A	1.04	.644	6394+	7500#
0212A	2.91	.589	8094+	9500#
0213A	4.13	.818	10644+	12500#
0214A	6.69	.906	1311+	1520#
0215A	7.24	.910	1031+	1190#
0219A	0.84	.516	42519+	50000#
0220A	1.07	.430	14469+	17000#
0221A	3.19	.774	42519+	50000#
0222A	1.47	.716	16849+	19800#
0223A	2.12	.780	28154+	33100#

Appendix D. Continued.

Sample No.	D	SD	TDS	SC
[illegible]224A	2.55	.787	11069+	13000#
[illegible]225A	2.55	.771	5119+	6000#

*Water sample taken on a different date than algae sample, either at the same site or a nearby site on the same water.

**Field conductivity measurement.

*TDS estimated from SC based on the regression equation X = 0.85Y + 19, where X is TDS and Y is SC.